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The Metallurgist.

Supplement to The Engineer, *April, 1935.*

The Institute of Metals.

INSTITUTE meetings are regarded primarily as occasions for the discussion of papers, and in this respect the March meeting of the Institute of Metals, by tradition a well-organised and successful function, fully maintained, and probably surpassed, the standard set by its predecessors. It is usual at such meetings for the business portion of the agenda to be dealt with in summary fashion, the briefest possible formalities being sufficient for the adoption of the various reports. In particular, the Report of Council, which the President, Dr. Harold Moore, referred to as having been written as concisely as possible in the hope of its being read, is in general accepted without any great show of interest on the part of the assembled members. This year, however, this relatively dull period of the proceedings was refreshed by some interesting discussion of finance and of the publication policy of the Institute. Within limits, such expressions of approval, appreciation, and constructive criticism are all to the good, and those whose responsibility it is to guide and direct must feel some gratification at such a display of interest in their work. It may be undesirable, however, for this innovation to develop and encroach on the time needed for the main purpose of the meeting. But the danger is small. In the past and present Reports of Council there should be, and probably is for most of the members, enough indication that wisdom and ingenuity are already being exercised.

Turning to the contents of the Report of Council, the outstanding impression given by that brief survey is that the Institute of Metals, in the face of damage to its overseas membership as a result of a period of widespread depression, has set an example of courage in sticking to its progressive policy. That this will pay in the long run there is no possible doubt. The spirit of service is always a good investment. Particular mention may be made of the latest innovation, the arrangement of Educational Tours for students, the first of which appears to have been highly successful. In the tour to the Rhineland this month, students have evidently had another valuable opportunity of extending their knowledge and outlook under most favourable conditions.

The Report cannot be dismissed without a reference to the results achieved by the policy of advance publication of papers and abstracts in the Monthly *Journal* of the Institute. This change is referred to as having been "an unqualified success," an opinion presumably based on the acknowledgments of members, and a marked improvement in the volume and quality of the discussions of the various papers. From the point of view of the Institute this must be gratifying, but it is questionable whether the wide view of the matter is, as yet, fully appreciated by the industries which, directly or indirectly, derive a great deal of benefit from the work of the Institute. It is an important principle that the discussion of published work is an essential corollary to the paper itself. In spite of careful scrutiny, much information of doubtful character may find its way into print, to the disadvantage of students and of industrialists by whom it may be applied. Competent criticism is not only the obvious safeguard, but also the best possible means of widening and adjusting the point of view of the scientific worker and that of the industry which is ready to apply the information. To this end, therefore, the progressive, if not venturesome, policy of the Institute of Metals seems to deserve the full approbation of engineers and manufacturers, as well as the extended support which is asked in return.

While on the subject of Institute activities, it is perhaps pertinent to mention a point of view concerning the respective fields of the two metallurgical sister Institutes. Much has been said on the theme that the arbitrary division of metallurgy into two sections is fundamentally unsound, and any further pursuance of the subject would only be tiresome. It is now generally accepted that "ferrous" and "non-ferrous" are terms of convenience which merely reflect the specialised character of the large field of alloys associated with the iron-carbon system. So far, both terms have remained without further subdivision, but it seems possible that this may come. The formation from time to time of specialist institutes indicates the trend which may result from progressive expansion of metallurgical knowledge.

Nowadays, specialisation, however undesirable, is increasingly difficult to avoid in any sphere, but in such a science as metallurgy there is particular reason to deplore any tendency to the formation of water-tight compartments. It is perhaps not fully realised, especially in industry, how largely the rapid advance of metallurgy during this century has depended on the width of view of workers familiar with both ferrous and non-ferrous branches of the subject.

From this point of view it is all to the good that the programmes of the Iron and Steel Institute and the Institute of Metals should continue to show evidence of the overlapping of their respective fields. The effects of molten metals in contact with stressed steel have been dealt with on more than one occasion by the Institute of Metals, while in the forthcoming meeting of the Iron and Steel Institute a paper dealing with the alloys of iron and aluminium may be of distinct "non-ferrous" interest. Although the membership of the two Institutes may not overlap as far as could be advocated, there is every probability that these papers will receive adequate general attention in one way or another. The suggestion

might well be made, however, that a more frequent arrangement of joint sessions of the Institutes would prove generally valuable, both for the immediate purpose of creating wider interest and discussion, and for the broader advantages of emphasising the singleness of metallurgical science.

Relation of Fatigue to Modern Engine Design.

A RECENT paper* on Fatigue and Engine Design deserves the close attention of engine builders, particularly those of marine engines, for whom it is primarily prepared. It possesses, however, a much wider interest as representing a valuable survey of certain aspects of the general fatigue problem, together with suggestions for directions in which future research may usefully be conducted. The paper consists of three distinct parts, each contributed by one of the joint authors, and concludes with a useful bibliography.

The first part of the paper is contributed by a well-known manufacturer of steel parts for marine engines. The author has three objects in view, *i.e.*, to demonstrate the service failures encountered by the marine engineer; to survey recent experimental data bearing on the problems involved in these failures; and to suggest the course of future investigations which appear desirable. Some typical failures are first described, illustrated by a large selection of excellent photographs. These include crossheads, various types of tail shafts, crank shafts, propellers, &c. It is shown that the chief initiating causes of failure met with in marine engine practice may be classed as follows:—Corrosion fatigue and impact, stress concentration effects arising at oil holes, caulking, corrosion pits, junction of dissimilar metals, fillets, surface conditions, internal stress, and deep tool marks. The author concludes from his experience that the avoidance of factors leading to stress concentration effects should be one of the principal concerns of the designer in order to reduce the number of service failures. An admirable review then follows of the published experimental work dealing with the effect on the fatigue range of stress concentrations, attention being properly drawn to the fact that the resulting reduction in strength depends not only on the form producing the concentration, but also on the material used. In the author's opinion much more research work remains to be carried out in this direction, particularly on steels in common use in marine engineering, together with some of the newer, lightly alloyed steels, not employing rolled bars from which to prepare the specimens but cutting these either from actual new forgings or from parts which have failed in service. It is suggested that the "damping characteristics" of materials should receive more detailed study in relation to their fatigue properties; and that much more attention should now be paid to the testing, under cyclic stresses, of models of machine parts of complex shapes. In surveying the present position of the subject, the author, while recognising that research workers in this country "have led the world in the scientific investigation of fatigue phenomena," suggests that they have rather fallen behind in the elucidation of the more technical considerations. He suggests that a planned investigation into the problems mentioned above would be worth while in an attempt to assist our marine engine designers in present-day conditions of higher speeds, lighter weight and multiplicity of available materials of construction.

Now these issues raised by the author are wide-reaching and merit the closest examination by all interested in the application of research to industry. Agreement must first be expressed with the suggested lines of research. If the effect has not yet been determined of various forms, producing stress concentrations, on the fatigue resistance of materials of interest to the marine engineer, this information should, and can easily, be obtained. Also, much more attention should be paid to tests on larger specimens and on models of complex shapes. The chief difficulty in this connection lies in the need for employing fatigue testing machines of much greater load capacity than are obtainable commercially in this country, but this is only a matter of cost, since machines adequate for any load can be easily designed, if required. The British research worker, as such, must surely be absolved from personal blame; he is rightly expected to provide ideas, and no one acquainted with the history of fatigue can admit that this country has not supplied a due share of new lines of attack upon the problem, but he does not usually supply the funds necessary for research. The ultimate responsibility must therefore rest with the sources from which funds for research purposes are drawn. In this connection, a direct and relevant comparison may be made. At the present time it is apparent that aircraft engines of British manufacture are second to none; they are being sold, and also manufactured under patent rights, in many of the principal countries of the world. In the design of such engines, the need to avoid fatigue failure is of paramount importance. Furthermore, the weight-power factor and the materials used impose problems much greater than those with which the marine engine builder is at present confronted. The means by which the present standard of reliability has been attained have been detailed in the pages of the Annual Reports of the Aeronautical Research Committee. They are the outcome of the great attention which has been paid to research both by the industry itself and in co-operation with researches—often State-aided—carried out in Government laboratories, universities, and manufacturers' works. These facilities continue to exist and are available equally to the marine engineer and to the aircraft or any other industry. But it is, of course, essential that the industry itself shall first recognise the existence and nature of its problems. The case as presented in the paper now under review certainly suggests that the marine engine builder cannot be absolved from responsibility for the present position. The author will have, indeed, performed a useful purpose if a programme of desirable research results, leading to steps being taken to make a vigorous attack on the problems.

Part II of the paper is contributed by a marine engine designer of great experience. He states that in oil engine construction the weight and space occupied have been reduced to nearly one-quarter of those of the practice of ten years ago without reducing the factor of safety, and that future development will lead still further towards reliability and reduction in weight, through ever-increasing attention to detail design. He expresses the opinion that reduced costs will result largely from increased efficiency in production rather than in simplified design, by using

* "The Relation of Fatigue to Modern Engine Design," R. A. MacGregor, W. S. Burn, and F. Bacon. N.E. Coast Inst. Engrs. Shipbdrs., Jan., 1935.

designs which in detail may be more complex, but are more scientifically correct in form. Here again we find a striking parallel to the development of the aircraft engine. The author suggests that this development can be greatly hastened by the use of special models subjected to laboratory tests.

A very valuable discussion then follows of the principles of engine design, particular attention being given to the chief forms which lead to stress concentration effects. This section is illustrated by useful diagrams indicating the stress distributions revealed by photo-elastic methods and "stress line" diagrams :—Grooves, holes, notches, fillets, collars, and screw threads, receive attention. The use of relieving grooves and internal fillets in producing improved stress lines is also shown in a very clear manner. Attention is drawn to the advantages obtained by the use of compound fillets in place of those having a single radius. In this connection it may be remarked that in such cases extreme care must be taken to avoid a discontinuity at the junctions of the component curves. Several cases are on record of service failures due to such incorrect machining, where the cure was worse than the ill. Informative sections of the paper deal with remarks on torsional oscillations, failures of rods owing to corrosion fatigue, and the inherent danger of the occurrence of fatigue failure at portions of forged steel parts where welding-on or welded deposits have been applied. A lengthy section dealing with materials includes discussions on forging and heat treatment, effect of fibre on fatigue endurance, crystal size, alloy steels and fatigue scale effect, effect of size on notch sensitivity, surface effect, and crack spread. With regard to the field for future research in fatigue with relation to the large marine engine, the author suggests that attention may usefully be paid to tests on models, internal and compound fillets, holes in shafts, relieving grooves, bolts and nuts of various forms, damping capacity in relation to notched-bar fatigue, grain size, degrees of forging with and without heat treatment, effect of grain direction on notched bar fatigue, combined stress, and scale effect, especially with regard to changes in form.

The third part of the paper is mainly occupied by brief discussions of fatigue in relation to Hooke's Law, elastic hysteresis and the "true" elastic limit, the significance of internal damping, &c. A plea is advanced for much further work on notched specimens of large diameter. A very short account then follows of the author's study of the mechanism of the spreading or propagation of fatigue cracks, suggesting that the simple geometrical forms of crack contour found in service failures under rotary bending can be reproduced in miniature under known and controlled conditions ; it is found that there are three or four sequences of crack contour which recur with remarkable consistency. The studies already made indicate that the rate of propagation of a fatigue crack of measurable size is remarkably consistent from specimen to specimen taken from the same bar. The author concludes that the major mystery of fatigue is not so much why cracks form at unsafe limits, but why they take so long about it ; he adds that the methods of solving this problem are emerging from the experiments now being conducted in his laboratory.

In the limited space available for a brief review it is, of course, quite impossible to do full justice to a comprehensive paper like the present. Enough has perhaps been said to indicate the general nature and scope of its contents. Its principal object is to focus the attention of those concerned with the design and production of the marine oil engine, both two-stroke and four-stroke, of several thousand horse-power, upon the importance of the fatigue aspect, and it will be exceedingly interesting to observe what action arises from the suggestions made. But does not a much larger issue demand attention ? Why not admit that the fatigue problem is one of the chief bugbears of all types of engine design, and not only that, but of all types of high-speed machinery, and frankly recognise that a host of problems which demand research attention are common to many industries ? These industries—either as such or through the major technical institutions—could usefully co-operate in the task of arranging a massed attack on these general problems. It is apparent to those intimately acquainted with fatigue phenomena that much wasteful duplication of effort is at present in progress, while important major problems lie neglected owing to the fact that the resources or interest of any individual research body are inadequate to provide the means for an attack on them.

Copper-Bearing Steels.

Copper-bearing steels have recently attracted attention, because of their corrosion-resisting properties and because they are susceptible to precipitation hardening. These two attributes of copper steels are, however, only incidentally mentioned in a paper on "The Influence of Small Quantities of Copper and Nickel on Carbon Steels," by H. Bennek, which has appeared in *Stahl and Eisen* (February 7th, 1935, Vol. 55, p. 160). The author of this paper is concerned with two different questions, viz., the effect on the properties of low-carbon and of high-carbon steels of such amounts of copper and nickel as may be introduced as an accidental impurity from the scrap, and secondly, the effect of a high copper content on the properties of the quench-hardened material.

The compositions chosen for experimental work comprised two series of steels containing approximately 0·1 and 0·9 per cent. of carbon, with 0, 0·04, 0·01, and 0·2 per cent. of either copper or nickel. To the high-carbon series were added another three steels with 0·5, 1 and 2 per cent. of copper respectively. The effect of these additions on behaviour in forging at temperatures up to 1300 deg. Cent. was first observed. All the steels with less than 0·2 per cent. of copper were entirely free from surface defects, while the high carbon steels with over 0·5 per cent. of copper showed surface flaws when the temperature of working was higher than 1000 deg. Cent. Hence, copper present as an unintentional impurity or in quantities up to 0·25 per cent. need cause no apprehension of forging difficulties.

The scale of copper-rich steels is known to contain metallic copper, but the copper content at which it first appears is not definitely known. Bennek states that he examined cross sections of his specimens and also their surfaces after removal of scale ; but that, when the material contained less than 0·25 per cent. of copper, he found no sign of a metallic deposit in or under the scale of steels which had been heated in an oxidising atmosphere at 750 deg. to 950 deg. Cent. for ten hours, or at higher temperatures for one hour.

Nickel, even when present in amounts not exceeding 0·25 per cent., was observed to reduce the amount of

scaling in both 0·1 and 0·9 per cent. carbon steels, but copper exercised a similar, though smaller, effect in the high-carbon steels only. The depth of decarburisation after heating at 1250 deg. Cent. in air

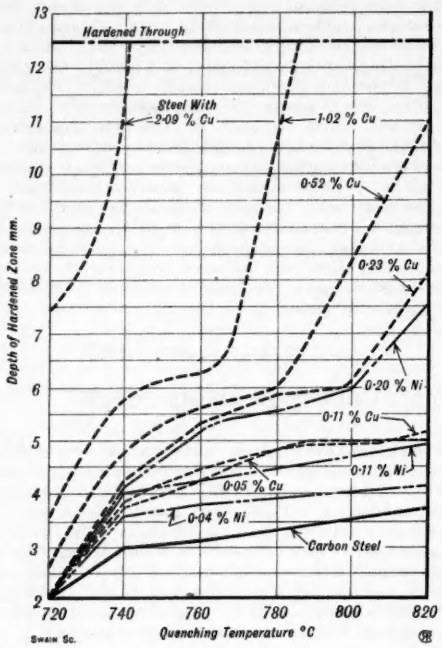


FIG. 1—*Effect of Copper and Nickel in Increasing Depth of Hardening of Steel with about 0·9 per Cent. Carbon.*

for one hour was about the same for copper and for nickel.

It is clear from the work of Buchholtz and Köster and of Nehl (see METALLURGIST, June, 1930, Vol. 6, p. 87) that, in steel with only 0·25 per cent. of copper, precipitation does not occur, or, at any rate, not to the extent of affecting the mechanical properties. Bennek found, however, that copper, like nickel, was not without effect on the properties of the normalised and annealed steels; thus, the tensile strength of 0·9 per cent. carbon steel was increased from 52·5 to 58 tons per square inch, and that of the annealed steel from 39 to 42·4 tons per square inch by the presence of 0·20 to 0·23 per cent. of copper or nickel.

These figures indicate that the capacity of 0·9 per cent. carbon steels for air hardening was not markedly increased by 0·25 per cent. of copper or nickel, and the effect on the 0·1 per cent. carbon steels was less; but the depth of hardening produced by quenching was definitely influenced by the presence of copper or nickel. With respect to the influence of copper, there has in the past been some difference of opinion. Grenet and Persoz have observed that high copper content increases depth-hardening in nickel-chromium steels. On the other hand, Stogoff and Messkin have stated more recently that copper in steels with 0·6 to 1·2 per cent. of carbon causes no increase in depth-hardening. Bennek has accordingly paid special attention to this point. Test pieces 25 mm. in diameter and 50 mm. long were quenched from temperatures between 700 deg. and 820 deg. Cent. in water at 20 deg. Cent., broken, and Rockwell hardness determined. When the test pieces were quenched from 740 deg. Cent. the depth of hardening increased with increasing copper content in much the same way as with an equal nickel content.

A copper or nickel content of only 0·04 to 0·05 per cent. was sufficient to increase the depth-hardening by 0·5 mm. or 0·75 mm. (15 to 25 per cent.), and with 0·2 to 0·25 per cent. of copper or nickel the depth of the hardened zone was increased by 1·2 mm. The hardening effects observed are shown in the diagram reproduced in Fig. 1, while Fig. 2 shows the appearance of the fractures of the 0·9 per cent. carbon steels containing copper or nickel, after they had been quenched from 740 deg. and 820 deg. Cent. The increased capacity for hardening is due to greater stability of the austenite, brought about by the presence of small quantities of copper or nickel and, shown by its reduced speed of transformation to martensite. Test pieces were quenched from 760 deg. Cent. in a salt bath at 270 deg. or 300 deg. Cent., and were held at that temperature. The changes in the magnetic properties of the steels in this condition are shown in Fig. 3. The steepness of the curve gives a measure of the speed of transformation of the austenite. With increasing copper and nickel content the curve is seen to become appreciably less steep.

No Alloy. *0.11 % Ni.* *0.23 % Ni.* *0.11 % Cu.* *0.20 % Cu.* *0.52 % Cu.* *2.09 % Cu.*

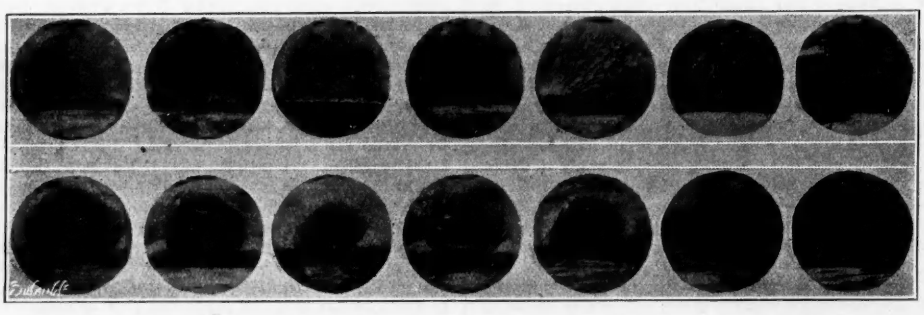


FIG. 2—*Appearance of Fractures of Water-Quenched Steels. Above:—Quenched from 740 deg. C. Below:—Quenched from 820 deg. C.*

Finally, it was found that small quantities of copper, up to 0·25 per cent., caused no increase in sensitiveness to overheating in the 0·9 per cent.

carbon steels. At 1 per cent. of copper there was a sharp drop in the temperature at which overheating begins, and as the minimum hardening temperature was only slightly lowered, the range of suitable hardening temperatures was narrowed down to 720 deg. to 800 deg. Cent. for a steel containing 0·9 per cent. of carbon and 1·0 per cent. of copper.

The work of Bennek seems to have established the fact that up to the limits within which they may be

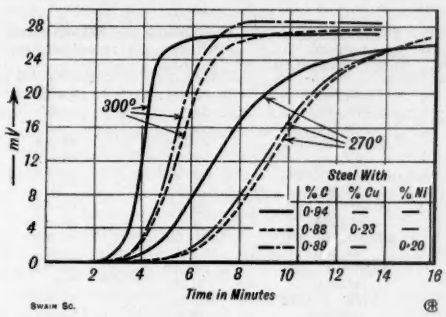


Fig. 3—*Influence of Copper and Nickel on the rate of Transformation of Austenite at 270 and 300 deg. Cent. (Magnetic Induction Measured by Deflection of a Millivolt Meter.)*

found as unintentional impurities in commercial steels—in fact, up to about 0·25 per cent.—copper and nickel are unlikely to lead to any manufacturing difficulties in steels of any carbon content. They produce no significant variation in the mechanical properties or normalised or annealed steels; but the increased capacity which they confer on the high-carbon steels for hardening on quenching is a matter to which attention may have to be paid in connection with steels for special purposes.

Platinum Alloys.

Although metals of the platinum group are regarded as very costly when compared with the commoner metallurgical products, they are, nevertheless, utilised in a number of applications for which their properties are particularly well and uniquely suited. Since little systematic information is available relating to their properties, the results of work carried out by E. M. Wise and J. T. Eash, which are given in Technical Publication No. 584 of the American Institute of Mining and Metallurgical Engineers, constitute a welcome and valuable addition to the subject. The compositions of the different alloys studied are indicated in the accompanying table. No. 1 platinum is the material which is widely employed for electrical contacts. The alloys of platinum with iridium are used for jewellery, and also for electrical contacts for operating under severe conditions. The alloy of platinum with 10 per cent. rhodium is used as a catalyst for ammonia oxidation, for crucibles, high-temperature furnace windings, electrical contacts and thermo couples. Alloys of platinum and iridium, and of platinum and rhodium are used also in electro chemical operations involving the liberation of halogens. The alloy of platinum with 5 per cent. nickel is used as a filament material in the long-life amplifying valves used in telephony. Palladium is also added to platinum for the production of contact material. Ruthenium is added to palladium as a hardener, and rhodium is added for the production of alloys required to take a brilliant polish.

All the materials tested were obtained as wire, 0·071in. diameter in the annealed condition, and cold drawn to a diameter of 0·050in., corresponding to a reduction in area of 50 per cent. At the latter thickness the wires were tested in the drawn condition and also after annealing, usually for five minutes, at different temperatures. The anneals were carried out in an electric furnace in air except those at 1100 deg. and 1200 deg. Cent., which were effected in a gas furnace. Specimens with a 2in. gauge length were used, and the reduction in area was measured optically. The results of tests on the wires in the drawn condition, and also after they had been subjected to what was considered the optimum annealing treatment, having regard to tensile strength, elongation, and surface appearance, are given in the table. With these metals the surface appearance is often an important consideration, and it is indicative of the grain size. Curves illustrating the effect of annealing temperature on tensile strength for platinum and platinum-iridium alloys show no marked abnormalities, and normal curves for limit of proportionality values were also obtained for these materials with the exception of the alloy containing 20 per cent. iridium where the departure from the normal may be associated with precipitation effects. Elongation values rise to a maximum, the temperature of which varies with the alloys, and fall away more gradually. The effect of annealing on the reduction of area is very slight. The figures given in the table show that nickel exerts a very pronounced hardening effect in platinum.

Palladium is stronger than platinum, both in the drawn and annealed conditions; but the cold-worked metal softens or anneals at a lower temperature. Ruthenium additions, as well as hardening palladium, have the effect of raising the annealing temperature and reducing the reduction in area values. The curves relating tensile strength and limit of proportionality for palladium and its alloys present, with one exception, no deviations from the normal. The tensile strength curve for the alloy of palladium with 4 per cent. ruthenium and 1 per cent. rhodium shows a maximum at about 800 deg. Cent., which may be a precipitation hardening effect. The elongation values of palladium reach a maximum at about 1000 deg. Cent., and the lower values obtained at higher annealing temperatures are attributed to the marked selective grain growth which has been observed. At annealing temperatures not in excess of 1000 deg. Cent., the grain size is small and uniform, but at higher temperatures it is very irregular. Although the cause of this has not been definitely established, it is possibly due to the presence in the alloy of traces of material which impede grain growth. The palladium alloys, however, do not show much falling off in elongation after annealing at high temperatures. Increasing the time of annealing of palladium at 830 deg. Cent. from five to thirty minutes in an air atmosphere caused a decrease in tensile strength of less than 3 per cent. and a reduction in elongation of only from 40 to 41 per cent. to 38 per cent. Similar results were obtained by annealing in hydrogen for thirty minutes and cooling in air, but specimens annealed in hydrogen and rapidly cooled in hydrogen were harder and

slightly less ductile than those annealed in air or in hydrogen and cooled in air. The tensile strength was increased from 30,000 lb. to 48,000 lb. per square inch, and the elongation on 2in. was reduced from 38 to 28 per cent. Annealing in nitrogen at 830 deg. and 900 deg. Cent. yielded similar results to those obtained on annealing in air. Slight surface discoloration occurred on palladium wires annealed in air, but not when they were annealed in hydrogen, nitrogen, or *in vacuo*, and it was only very slight on the alloy containing 3 per cent. rhodium and 2 per cent. ruthenium after annealing in air.

Properties of Platinum Metals and Alloys, Cold-Drawn (50 per Cent. Reduction) and After Recommended Anneals.

Material.	Recommended 5 min. anneal, deg. Cent.	Limit of proportionality, lb. per square inch.	Ultimate tensile strength, lb. per square inch.	Elongation, per cent. on 2in.	Reduction of area, per cent.
Com. Pure Pt	900–1,000	27,000 10,000–5,300	36,000 24,000–22,000	2·5 24–34	95 92
No. 1 Pt	1,050–1,100	27,000 8,500–6,500	36,700 25,000–23,000	3·5 21–29	96 94–95
Pt 95, Ir 5	1,100–1,200	53,000 23,000–18,000	69,100 41,500–39,000	2·0 22–32	92 95–94
Pt 90, Ir 10	1,100–1,200	54,000 36,000–30,000	82,200 55,000–53,000	2·5 25–27	94 95–94
Pt 80, Ir 20	1,200–1,400	100,900 62,000–59,000	140,500 102,000–93,000	2·5 21–20	84·5 89–88
Pt 90, Rh 10	1,100–1,200	55,600 22,000–17,000	84,300 49,000–47,000	3·0 25–37	90 93–94
Pt 75, Pd 20, Rh 5	1,000–1,100	51,900 23,500–17,000	85,000 57,000–53,000	1·75 23–29	87 91–94
Pt 95, Ni 5	1,000	70,000 33,000	103,100 65,000	2·0 23·5	84 93
No. 1 Com. Pd	800–900	31,800 5,000	46,900 30,000	1·5 39–41	91·5 92–89
Pd 95, Rh 3, Ru 2	1,000–1,100	46,050 16,000–15,500	61,000 46,000–41,000	2·0 30–36	88·5 92–88
Pd 95, Ru 4, Rh 1	1,000–1,100	46,300 28,000–21,000	71,500 59,000–55,000	3·0 23–26	84·5 84

The Structure of Metallic Coatings, Films and Surfaces.

THE chemical and physical properties of metallic surfaces may differ in many ways from those indicated by tests which give the average physical properties or the chemical properties of the underlying metal after removal of surface films. The behaviour of metals in a fatigue test, for example, has been shown to be affected by the method of preparation of the surface, and the resistance to various corrosive media is often influenced and sometimes controlled by the thin oxide layer formed on exposure to air. Further knowledge of the structure of surfaces and of metallic coatings (which are being applied to an increasing extent for decoration and for protection against wear and corrosion) is thus of considerable value at the present time. The General Discussion on this subject held by the Faraday Society on March 29th and 30th affords an indication of the many recent advances, both in methods of study and in knowledge obtained.

The discussion was primarily directed towards methods of determination of the structure of surfaces, and consequently the electron beam diffraction method attracted considerable attention. This method, largely due to Professor G. P. Thomson, has the peculiar advantage that the penetrative power of the electron beam is small, and the effects observed are confined to the surface of the material. The method appears likely to form a valuable tool for the metallurgist as well as the physicist in the investigation of surface structure.

The exhaustive paper by Finch, Quarrel, and Willman described and discussed the technique of the electron beam diffraction method, as well as giving a number of the results obtained, many of which are of considerable interest to metallurgists. An interesting suggestion was made that the "extra" rings and bands sometimes noticed in electron diffraction patterns were due to expansion of the lattice by the entry of gas, either as solid solution (extra bands) or as a compound (extra rings). From these results, it appeared that the surface of aluminium, for example, is capable of absorbing oxygen on heating in air and of losing it on heating in hydrogen or *in vacuo*. This suggestion aroused some controversy in the discussion.

Probably one of the most interesting features of the electron diffraction papers was the confirmation of the hypothesis of the "Beilby layer," produced on polishing metal surfaces. Beilby investigated the action of the polishing process, using microscopical methods, and came to the conclusion that the surface of a polished substance was covered with an amorphous layer, chemically identical with the underlying material, but devoid of crystal structure. He considered that during polishing mobility was imparted to the surface, which flowed like a liquid and rapidly congealed without crystallising. Objections have been raised to this hypothesis, and many metallurgists and physicists have tended to accept the view that the polished layer consists of minute crystals. The results given in this discussion, however, show that the electron diffraction method confirms Beilby's original hypothesis, as far as metals are concerned. Finch and his collaborators showed that the polished surface of copper, and to a lesser extent of other metals, behaved like a liquid in dissolving certain thin crystalline metal films. For example, electrodeposition of zinc for 30 seconds at 0·1 amp./dm.^{2} was sufficient to form a permanent crystalline zinc layer on crystalline (etched) copper, but deposition for 3 minutes was necessary on polished copper if the crystalline zinc pattern was to be retained. Hopkins, who presented a useful summary of previous work on the Beilby layer, and also Lees, attempted to deter-

mine the thickness of the layer. The method consisted in photographing the diffraction pattern of the polished metal (Hopkins used gold), removing a known thickness of metal, and again photographing the pattern, until the normal sharp pattern was obtained. One of the chief difficulties of this method is the choice of means for removing a known thickness of metal without otherwise modifying the chemical or physical properties of the surface. Hopkins chose the cathodic sputtering method, the rate of removal being previously determined under standardised conditions with the aid of a micro-balance. This method aroused less criticism than Lees' method of anodic dissolution which is known to be liable to cause the formation of oxide films, and the only criticism of the sputtering method was that the local heating produced might have altered the characteristics of the Beilby layer. Hopkins concluded that the average thickness of the Beilby layer produced on gold by smoothing on successive grades of emery paper and finally rubbing on clean chamois leather was about 30 Å. Below the polished layer the crystals gradually increased in size, but even at a depth of 100 Å they were still extremely small

Many other interesting applications of the electron beam diffraction method were mentioned—for example, the examination of liquids, floating films, scums or slags, oxide films on metals, and graphite. Cast iron, of the quality used in internal combustion engines, showed a layer of graphite spread over the surface after rubbing with fine emery. An examination of used cylinder liners from aeroplane engines suggested that the process of running-in an internal combustion engine consists in the formation on the working surfaces of an amorphous Beilby layer of considerable depth.

The results, briefly referred to above, indicate the possibilities of the electron beam diffraction method, and suggest the importance of the further knowledge which it appears capable of providing on the structure of metallic surfaces.

The paper by Andrade on the mobility and crystallisation of thin gold and silver films, investigated with the aid of the microscope, provided a fitting link between the discussion of electron diffraction and optical methods. Methods using waves of visible light and electron waves respectively can be considered as supplementary, the one being too coarse to record fine effects and the other too fine to record coarse effects.

It is now well known from the work of Evans and others that metals form oxide films on exposure to air which affect or control their behaviour in corrosion. Tronstad and Ornstein are well known for their valuable contributions to the development of optical methods of studying the formation and structure of such films. Tronstad, who has previously discussed, before the Faraday Society, the value of Drude's optical method of investigating transparent films on metals, gave further information on the usefulness of this method, which has the peculiar advantage of allowing the study of the formation and changes of films *in situ* and in prescribed environments; his paper discussed the validity and applicability of the method.

Many of the papers dealing with the structure of electro-deposited coatings proved of considerable interest and provide a notable contribution to the science of the subject. It is over ten years since the Faraday Society held its last discussion on electro-deposition, and the papers presented showed the remarkable advance in the knowledge of the subject which has been made in the past decade—evidence of the considerable interest which has been aroused in electro-deposition.

In addition to their application for decorative and protective purposes, certain electro-deposited coatings are finding an increasing use for facing metals for protection against wear, thus enabling metals to be used which are unsuitable for wear resistance, but possess advantages in low cost, ease of casting, light weight, suitable physical properties, &c. Although certain problems remain to be solved before such applications can become widespread (in particular, that of adhesion to light alloys and zinc-base die castings), advantage has already been taken of the high hardness and resistance to tarnish of chromium in the engineering and printing industries, where this metal is used as a thin facing (usually less than 0·001in. in thickness) for the protection of gauges, press tools, photogravure cylinders, &c. These and other applications have encouraged investigations of the structure and properties of electro-deposited metals.

The high hardness obtainable with many electro-deposited metals has aroused interest for a long time, especially since the application of quantitative hardness tests showed that a number of metals could be obtained in a far harder condition by electro-deposition than by mechanical working. Macnaughtan some time ago advanced the view that the hardness was due to small grain size, but it was fairly generally thought until recently that co-deposited hydrogen was the main cause of the small grain size. Suggestions have been made from time to time (notably by Oesterle in 1928 and O'Sullivan in 1930) that the inclusion of hydroxides in the deposit might be a factor responsible for modifying the properties, and Macnaughtan and his collaborators were able to prove the correctness of this view by the application of quantitative tests to deposits prepared under carefully controlled conditions; the presence of non-metallic material in the deposits was established by micro-examination after annealing *in vacuo*, grain growth being restricted and segregation of non-metallic matter to grain boundaries taking place to a degree corresponding with the hardness of the deposit. These results, and the methods used in obtaining them, were described by Macnaughtan and Hothersall.

Results given by Wood, obtained by X-ray analysis, indicated that the hardness of nickel and chromium deposits may be due either to minute grain size or to lattice distortion. The question was raised by Desch, in his very useful introductory survey of the papers, as to whether microscopical examination suggested a grain size small enough to account for the observed effects and whether the grain size measured by the X-ray method did not correspond with an internal mosaic structure of smaller dimensions than that indicated by the microscope. A further possibility, previously suggested by Desch, was that the non-metallic matter, now proved to be present in certain deposits, may be finely dispersed through the crystals and may be partly responsible for hardness by a mechanism similar to that of the age-hardening of alloys.

Additional light on the structure of chromium deposits was thrown by Wright, Hirst, and Riley, who provided further proof, using X-ray methods, of the existence of a hexagonal modification of chromium; they were also able to show that the formation of this modification is encouraged by the presence of tervalent chromium compounds in the solution. This new information is of interest and a

correlation of these results with the properties of, and presence of defects in, the deposit might be of considerable practical value. Information on the mechanism of chromium deposition was provided by the summaries by Liebreich and by Müller of their extensive electro-chemical researches carried out in Germany.

Differences in the physical properties of electro-deposits produced by the presence of different anions in the solution have been noted by various investigators—notably by Glasstone (in silver deposits), and by Macnaughtan and his colleagues (in nickel deposits). Some further information was given in the paper by Schloetter, who claimed that the anion is sometimes included in the lattice of the deposited metal, the chemical properties of which may then be modified to a marked degree; for example, silver deposited from an iodide solution was found to have a golden colour and to be resistant to staining by reagents containing sulphur.

The relation between the structure of a basis metal or substrate and that of a coating formed upon it is a subject of great importance, since it can provide information not only on the probable influence on the structure of an electro-deposit of a body which is included in the growing lattice, thus altering its dimensions, but also on the nature of the adhesion between an electro-deposited coating and the base. Thin films deposited by sputtering and examined by electron diffraction methods were found by Finch to take up a similar orientation to that of the base—a conclusion also reached previously by Wood by X-ray methods for nickel and copper electro-deposited under certain conditions upon copper. Microscopical evidence of continuation of structure was provided in the papers by Hothersall and Portevin. Hothersall found that the microstructure of a deposit could continue that of the base even though there was a considerable difference in lattice dimensions and crystal type; he showed examples of the continuation by electro-deposited copper (face-centred cube, 3·61 Å) of both annealed nickel and silver (face-centred cubes, 3·52 Å and 4·06 Å respectively), and by electro-deposited tin (tetragonal) of annealed copper. From these results it appears probable that the high degree of adhesion obtainable with electro-deposited coatings is associated with their ability to build up the lattice of the metal upon which they are deposited in preference to the formation of a random arrangement to constitute the nuclei of a new structure. That continuation of structure is not always seen under the microscope may be due to a change in structure to that of the normal electro-deposit owing to interference caused by the inclusion of foreign bodies—for example, colloids.

Much of the increased attention given to the process of electro-plating owes its origin to the work of Blum and his associates at the Bureau of Standards. In a paper by Blum and Kasper, the properties of nickel deposited at high current density from plain nickel chloride and sulphate solutions were examined. The results are of practical value to the printing trade, where the rapid production of thick deposits of suitable mechanical properties is of importance.

Improvement in the quality of hot-dipped coatings was recognised by Daniels as involving a fundamental study of the process, and his paper forms a useful addition to the knowledge of the process. Daniels reviewed and discussed the factors influencing wetting of the basis metal by the coating metal, the fluxing reaction, and the structure of the interfacial alloy and its modification by the presence of small amounts of other metals in the liquid coating.

The porous nature and poor adhesion of sprayed coatings were referred to by Reininger, and the improvement in these properties effected by the incorporation of a suitable varnish in the coating was examined.

In this brief review, mention of some of the papers has of necessity had to be omitted. The field covered was too wide for adequate discussion at the meeting of all the papers presented, but the Faraday Society is to be congratulated on successfully collecting together the latest expert information on structure of surfaces and coatings which is ordinarily widely dispersed in the literature, but which has an interest common to both metallurgists and physicists.

Cold Pressing and Drawing.

WITHIN a period of a few years only, methods of engineering design, in certain directions, have been drastically affected by the rapid development and employment of two methods of construction, namely, welding and cold pressing. In each case, it may fairly be said that technical development has proceeded at such a pace as to outstrip the rate of accumulation of knowledge of the basic principles involved. It is certainly no new situation in engineering to find that an important process must be regarded as an art rather than as a science; nevertheless, at some stage, a need is generally felt that the time has arrived when serious attempts should be made to survey the position and establish technical rules in order both to stabilise the existing position and to provide guidance for future developments. Often a useful first step is taken by the collection of experiences and views through the medium of a "discussion" by the various interests concerned. From such a survey important avenues of attack on the problem are often found. A week hence there will be held a noteworthy international symposium and discussion on welding, organised by the Iron and Steel Institute with the co-operation and support of the other leading technical institutions of this country. A review of this interesting event will appear in a future issue of THE METALLURGIST. Equally interesting in nature, although much more modest in scope, was the joint discussion on cold presswork held in London on March 5th, organised by the Institution of Automobile Engineers in co-operation with eleven other technical institutions.

Three papers* by Drs. Gough and Hankins, Dr. Desch, and Dr. Sachs respectively, were presented, in summarised form,† by the authors and followed by a general discussion.

The paper by Gough and Hankins, after presenting an interesting discussion of the general problems associated with cold-pressing operations, describes in detail a general experimental investigation into the fluid pressure cupping test as a means of ascertaining the suitability of sheet metal for deep pressing purposes. In this test—originally due to Jovignot‡—a sheet specimen is gripped firmly in an annular

* (*a*) "A Research into Tests for Materials Used in Cold-Pressing Operations, with Special Reference to the Fluid-Pressure Cupping Test," H. J. Gough and G. A. Hankins; (*b*) "Cold Pressing and Drawing: The Metallurgical Aspect," C. H. Desch; (*c*) "New Researches on the Drawing of Cylindrical Shells," G. Sachs.

† The papers are published in full in the March *Journal* (No. 6, Vol. III, 1935) of the Inst. Auto. Engrs.

‡ *Comptes Rendus*, Vol. 190, 1930, p. 1299.

die and is distended, by fluid pressure applied to one of its faces, until fracture occurs. Experiments were first carried out on a commercial machine, using die diameters of 40 mm., 50 mm., and 60 mm.; but undesirable restrictions were imposed on the thickness of sheet which could be satisfactorily tested. Accordingly, a new form of machine was designed and constructed, fitted with dies up to 100 mm. in diameter, and capable of applying fluid pressures of 5 tons per square inch; means of obtaining autographic load deformation diagrams were also fitted. It was established that the sheet metal specimen deformed into a dome which was an extremely close approximation to a spherical segment, thus investing the test with the important advantages: (*a*) That the deformed specimen always has the same simple geometrical external shape, (*b*) that the breaking stress can be approximately estimated, using the thin sphere formula. Owing to edge constraint, however, the specimen does not deform uniformly throughout in thickness, and for this, and other obvious reasons, geometrically

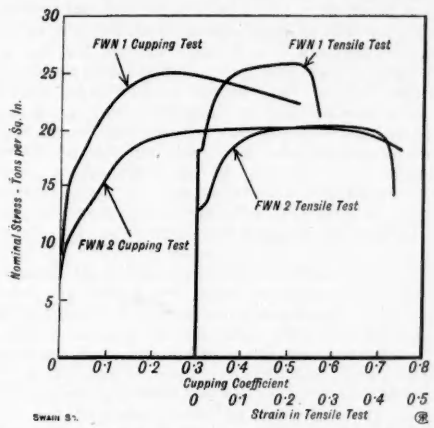


FIG. 1—*Stress-Strain Curves. Material FWN 1 and FWN 2.*

similar conditions are not realised in specimens of the same material tested with various die diameters. Some attention was given to this aspect; it was concluded that with the materials and sheet thicknesses used, similar results from this form of test may be expected provided the die diameter exceeds 50 mm.; this is an important aspect which may profitably receive further attention. The autographic diagrams record the relation between the height of the dome and the applied fluid pressure. By arithmetical methods, such a diagram can be converted into a curve showing the relation between the nominal tensile stress in the material and the superficial strain. It is to this type of diagram that the authors attach major importance, suggesting that the suitability of a material for cold-pressing operations is probably associated with the form of this "stress-strain" curve. In addition to examining the behaviour under the fluid pressure cupping test of a representative series of ferrous and non-ferrous metals and alloys, tests were also made on a few materials about whose service behaviour some data were available. Fig. 1 refers to two samples of mild steel, one of which—F W N 1—had proved unsatisfactory for deep pressing operations, while the other sample—F W N 2—was satisfactory. The diagram also includes the results of static tensile tests made on the same materials. Fig. 2 similarly refers to two samples of stainless steels, H B I 1 and H B I 2, which, it was stated, had behaved unsatisfactorily and satisfactorily, respectively, in the press. In each pair of materials, striking differences are encountered in the form of the stress-strain curves. It is interesting to note that the cupping test curves reflect the tensile

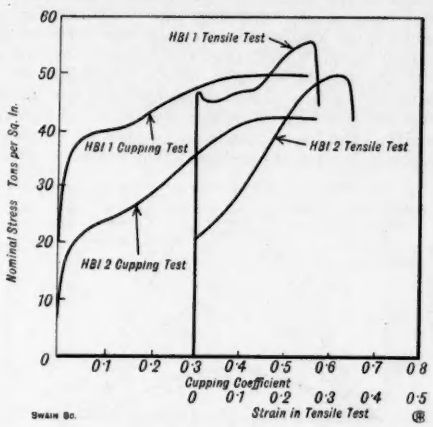


FIG. 2—*Stress-Strain Curves. Materials HBI and HBI 2.*

characteristics. As the plastic properties of a material are of primary importance in pressing operations, mere inspection of these curves does suggest that the relative suitability of these materials may be indicated by the relative forms of the stress-strain curves. The authors of the paper take the attitude that the whole matter requires much further investigation, but that the results already obtained appear sufficiently promising to merit such further work. They do not attach great value to the mere determination of the value of the Jovignot "cupping coefficient" (*i.e.*, average unit increase of surface area at fracture), but consider that this should be studied in relation to the nominal stress. In other words, the real criterion is the form of the complete nominal stress-superficial strain relation. This conclusion receives support from an examination of the results obtained in an investigation of the various measures of "ductility" afforded by the following forms of tests:—Erichsen, Avery, Guillery, "A.E.G.," "K.W.I.," in comparison with the Jovignot cupping coefficient. Plotting the results obtained with these various forms of test using a variety of materials, it may be said that, in general, much the same type of curve was obtained.

The second paper, by Dr. Desch, was in the nature of a brief survey of the metallurgical aspects of the problem of providing suitable material for deep pressing operations. An interesting account is given of some aspects of deformation, of "stretcher strains," ageing of cold-worked steel, of sheet steel production and heat treatment, texture, &c. The author concludes with the opinion that progress, especially in regard to steel, will result from a thorough investigation of the metallurgical condition of the material at each of its various stages, beginning with an improvement in ingot structure.

Dr. Sachs' paper is a valuable *résumé* of experi-

mental studies aimed at increasing the maximum draw obtainable, in a single operation, in the production of cylindrical shells. It is concerned entirely with the mechanical aspects of the drawing of this particular article. Some of the variables which have received careful attention include the following :— Clearance between punch and die, radius of die and punch, form of blankholder and blankholder pressure. In a discussion of the stresses and strains induced in the material, it is pointed out that, to ensure satisfactory drawing, the maximum stress induced must always be less than the value of the breaking strength, but that the latter is not necessarily the tensile strength of the material. It is dependent on the sheet thickness and the punch curvature, and may be greater or less than the tensile strength. Making certain assumptions, an empirical relation is developed for the drawing force. In Fig. 3

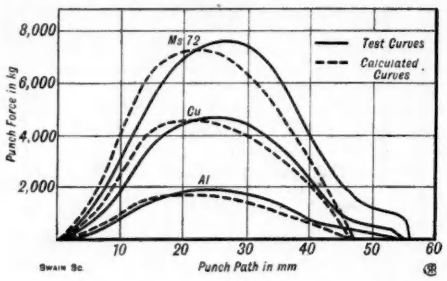


FIG. 3

the values calculated from this formula are compared with those obtained experimentally; fairly good agreement is apparent. Fig. 4 shows the very considerable improvement in reduction obtained in a single draw under mass production conditions. This improvement has been effected " in the course of the last decade."

In discussing means of testing the suitability of materials for deep-drawing steels, the author states that German experience indicates that tests such as the Erichsen cupping test have proved quite satisfactory, but give results essentially the same as the tensile test, which is more easily carried out.

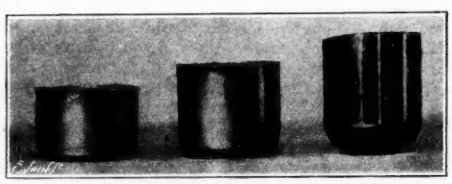


FIG. 4

This is an important conclusion which deserved amplification. It is certainly not the experience in this country that the Erichsen test is sufficiently discriminating for deep-pressing operations in general. Dr. Sachs also refers to the " wedge-drawing " method of testing developed in Germany and America, and states that the utility and practicability of this type of test has been demonstrated by various workers.

Dr. Sachs' paper is valuable and informative; it represents a careful technical study of the production of one particular article, the cylindrical shell. But it must be remembered that it affords little guidance, if any, to the production of cold pressings in general, especially those of irregular and complicated forms; the author recognises this frankly. It is inconceivable that each particular form of pressing can receive an equally exhaustive experimental treatment. If the lessons derived from this study of cylindrical shells cannot be applied to the general problem, there appears to be a case for an investigation of a more general nature.

The discussion which followed the presentation of the papers naturally touched a wide range of aspects. For example, attention was drawn to the importance of adequate lubrication of dies, while it was agreed that certain general metallurgical requirements, such as grain size, &c., were recognised as essential. But the discussion primarily centred round the need for an adequate method of mechanical testing of the sheet which would be capable of discriminating suitable from unsuitable material. Apparently, no existing test method has been found satisfactory in this respect. There is a real and urgent need for a reliable acceptance test for the sheet material. Great interest was evinced in the complete cupping test devised at the N.P.L. and described in the first paper. This method of test certainly appears to deserve further investigation. It may prove that—as suggested by Gough and Hankins—the stress-strain curve given by the fluid pressure cupping test principally reflects the characteristics of a complete tensile stress-strain curve. If this conclusion were to emerge, the position would be quite satisfactory, reducing to the simple question of whether the cupping test, possessing the advantages of requiring no preparation of the specimen and giving a result in terms of superficial strain, is simpler and cheaper to carry out than the number of complete tensile tests necessary to determine the characteristics of the material in several directions.

This general discussion of an important technical subject was undoubtedly very successful in its object of reviewing the general nature of the problem of cold pressing, and indicated some of the lines along which research attention can usefully be directed. A large number of industries interested in cold presswork were powerfully represented; the Institution of Automobile Engineers, as the organising body, together with the eleven co-operating technical institutions, are to be congratulated on having provided such an interesting and useful evening.

High-grade Aluminium.

MUCH of the Institute of Metals Autumn Lecture in 1926 was devoted by the late Dr. Rosenhain to a discussion of advances made in the production of pure metals. Dr. Rosenhain dealt with the then recent achievement by which the purity of commercially produced aluminium had been raised from 99·7 to 99·95 per cent., and on this and other occasions he commented on the remarkable change in properties which might be expected to occur in this or in any other metal as it approached a perfectly pure condition.

These forecasts are entirely justified by the characteristics of " *aluminium raffiné.*" One of the earliest of its properties to be observed was its

extraordinary resistance to corrosion and to acid attack. Now, further evidence of its exceptional properties is provided in a note on "The Annealing of Aluminium and its Possible Use as a Criterion of the Purity of the Metal," by Jean Calvet, communicated by Dr. Guillet to the Académie des Sciences (*Comptes Rendus*, January 2nd, 1935, Vol. 200, pp. 66–68).

It is known, as the author observes, that the presence of impurities in a metal decreases the rate of annealing after cold work. In order to study this effect in a series of specimens of refined aluminium (varying from 99·96 to 99·9986 per cent.) he compared their rates of annealing after they had been subjected to an identical cold-working treatment. The specimens contained the usual impurities—iron, silicon, and copper—which could be estimated by colorimetric methods. Their arc-spectra showed, in addition, the presence of a very small amount of magnesium. The 99·9986 per cent. specimen is referred to as the best metal made in France up to the present.

The method of cold working adopted was cold rolling from the ingot, the thickness being reduced from 20·4 mm. to 1·5 mm. in ten passes. Absolute identity of treatment was realised to be essential, and precautions were taken to avoid, as much as possible, any heating of the metal during rolling or during the preparation of specimens for tensile tests.

The tensile strength of the rolled materials, before they had undergone any annealing, showed a regular increase as the amount of impurity increased :

Aluminium content, per cent.	Tensile strength, kg./mm².
99·9986	12·68
99·997	13·33
99·996	13·90
99·995	14·10
99·99	14·55
99·98	14·80
99·96	15·98

A more pronounced difference between the materials was, however, shown by their rates of annealing. The behaviour of the purest specimen of aluminium is shown in the large table. After the standard amount of cold work specified above, annealing of aluminium of 99·9986 per cent. purity was complete after 6 to 10 minutes at 100 deg. Cent. The softening effect was still rapid at 16 deg. Cent., and in time the metal showed a high value of elongation. Even at 0 deg. Cent., and probably at a still lower temperature, the decrease in the breaking load was clearly marked.

As the amount of impurity increased, the rates of annealing diminished in a striking manner. For example, at 100 deg. Cent. the 99·997 per cent. aluminium is still not completely annealed after 6 hours. When the aluminium content falls to 99·996 per cent. the rate of annealing at 100 deg. Cent. becomes very small ; after 240 hours the breaking load diminished only by 17 per cent., and the elonga-

TABLE.—*Tensile Strength and Elongation of* 99·9986 *Per Cent. Aluminium.*

Time at 130 deg. Cent.	0	15 sec.	30 sec.	45 sec.	2 min.	1 hr.
Tensile strength, kg./mm.²	12·21	6·89	5·88	5·14	5·17	5·01
Elongation, per cent.	8·5	34·3	41·1	46·4	51·1	51·4
Time at 130 deg. Cent.	6 hr.	14 hr.	43 hr.	113 hr.		
Tensile strength, kg./mm.²	5·09	5·43	5·12	5·17		
Elongation, per cent.	48·9	49·3	50·0	61·8		
Time at 100 deg. Cent.	0	45 sec.	2 min.	6 min.	10 min.	1 hr.
Tensile strength, kg./mm.²	12·97	7·22	5·99	5·40	5·19	5·37
Elongation, per cent.	6·2	18·5	43·3	46·3	50·0	54·4
Time at 100 deg. Cent.	6 hr.	24 hr.	72 hr.	120 hr.		
Tensile strength, kg./mm.²	5·40	5·08	4·94	5·08		
Elongation, per cent.	55·5	55·9	51·8	50·9		
Time at 80 deg. Cent.	0	2 min.	10 min.	20 min.	1 hr.	6 hr.
Tensile strength, kg./mm.²	12·44	8·42	6·22	5·32	5·34	5·03
Elongation, per cent.	8·4	11·5	31·5	43·8	47·7	46·1
Time at 80 deg. Cent.	16 hr.	24 hr.	48 hr.	96 hr.	168 hr.	192 hr.
Tensile strength, kg./mm.²	5·11	5·03	5·23	5·11	5·22	5·02
Elongation, per cent.	53·8	49·6	54·6	51·9	55·7	53·1
Time at 60 deg. Cent.	0	10 min.	1 hr.	2 hr.	6 hr.	24 hr.
Tensile strength, kg./mm.²	12·69	9·02	6·52	6·83	5·71	5·58
Elongation, per cent.	9·0	16·1	23·1	19·1	42·3	42·3
Time at 60 deg. Cent.	48 hr.	96 hr.	192 hr.	312 hr.	384 hr.	
Tensile strength, kg./mm.²	5·82	5·41	5·48	5·26	5·61	
Elongation, per cent.	53·8	40·4	47·3	40·4	44·2	
Time at 40 deg. Cent.	0	10 min.	1 hr.	6 hr.	24 hr.	48 hr.
Tensile strength, kg./mm.²	12·51	12·32	10·54	7·73	7·17	6·30
Elongation, per cent.	8·1	8·1	9·2	22·2	22·9	32·2
Time at 40 deg. Cent.	96 hr.	192 hr.	384 hr.			
Tensile strength, kg./mm.²	6·90	6·11	6·61			
Elongation, per cent.	35·2	34·8	32·2			
Time at 16 deg. Cent.	0	40 hr.	96 hr.	192 hr.	480 hr.	4128 hr.
Tensile strength, kg./mm.²	12·86	8·72	7·94	8·71	7·11	6·75
Elongation, per cent.	9·2	17·8	16·4	21·4	37·5	42·8
Time at 0 deg. Cent.	0	48 hr.	96 hr.	192 hr.	480 hr.	
Tensile strength, kg./mm.²	12·86	11·08	10·40	9·47	8·77	
Elongation, per cent.	9·2	9·3	12·5	15·0	12·8	

tion had not begun to increase. Even at 175 deg. Cent. complete annealing required about 48 hours. In this connection it should be noted that a fall in aluminium content of 1 part in 100,000 represents a very big percentage increase in the actual amount of impurity present, and this makes the pronounced effect on the properties of metal less surprising.

In dealing with a less pure metal, the temperature required to obtain rapid softening must again be raised. Aluminium of 99·99 per cent. purity is not quite completely annealed after one hour at 225 deg. Cent. To produce a similar result, 99·98 per cent. aluminium requires over 24 hours at this temperature, and the 99·96 per cent. metal was incompletely annealed after 100 hours.

The results of these experiments suggest that a study of the rate of annealing after cold work may constitute an extremely sensitive means of determining the degree of purity of refined aluminium. The metal containing 99·9986 per cent. aluminium shows rapid spontaneous annealing at atmospheric temperature. M. Calvet's work illustrates the very important part played by small quantities of impurities in aluminium, and leads him to suppose that aluminium, completely deprived of impurities, may possess properties in relation to cold working and annealing which approximate to those of lead.

The Evaporation Process for Mirrors.

By L. H. J. PHILLIPS, B.Sc., A.M.I.E.E.*

IT is probably true to say that the high vacuum evaporation process for the production of mirror surfaces owes its present commercial development to the incessant demands of astronomers and solar physicists for a mirror surface of which the material does not possess the disadvantages associated with silver. Silver has always been regarded as the standard metal for ordinary domestic and decorative mirrors, due mainly to the fact that it may be chemically deposited fairly easily; in addition, tarnishing is minimised by the use of heavy protective layers on the back of the mirror. When astronomical mirrors are considered, however, it is seen that silver is definitely unsuitable. In the first place, such mirrors have the reflecting surface at the front; that is, the silver reflects directly and not through the glass and consequently cannot be protected in any way. As a result the tarnish problem becomes very important. Further, when metal mirrors of accurate figure are used, it is undesirable that they shall be immersed in deposition baths in case the reagents employed are such that they attack the parent metal of the mirror.

Silver has other disadvantages when used as a surface coating for astronomical mirrors. For example, the surface deteriorates very badly when in contact with moisture and it cannot be easily cleaned without damage. Worst of all, however, from the point of view of the solar physicist, is the fact that the reflectivity of silver is poor in the ultra-violet region of the spectrum, particularly around 3100 Å. Fig. 1 illustrates this.

Such considerations have led to many investigations into the possibility of using other metals for the reflecting surface of astronomical mirrors, and comparatively recent work has indicated that aluminium would be practically ideal for this type of work.

The use of this metal, however, necessitated a different technique and process for depositing it as a thin film, and successful experimental work was carried out on vacuum evaporation in 1929 in the Physikalische Technische Reichsanstalt, Berlin, and in 1930 and 1931 at Cornell University and the Californian Institute of Technology. The investigators in these institutions showed definitely that it was possible to deposit on glass films of silver, aluminium, and aluminium-base alloys, and chromium. It is claimed that the mirror surfaces so produced are uniform and free from pits, a statement confirmed by more recent work in the research laboratories of the Metropolitan-Vickers Electrical Company. In particular it has been found that aluminium fulfils practically completely the needs of astronomers.

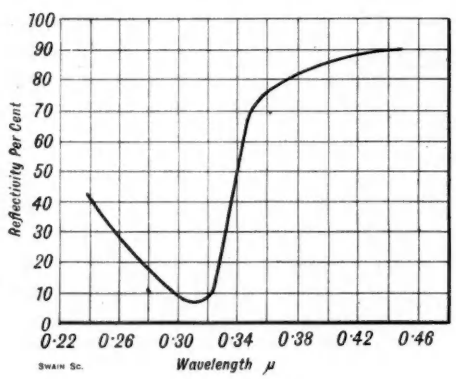


FIG. 1 (*Silver*).

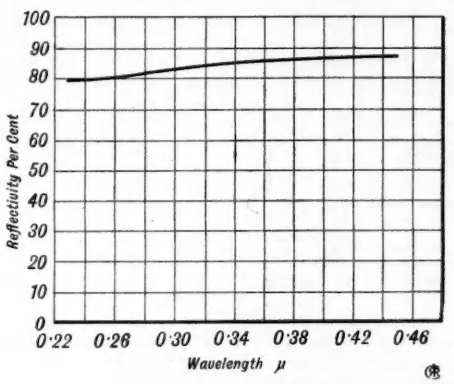


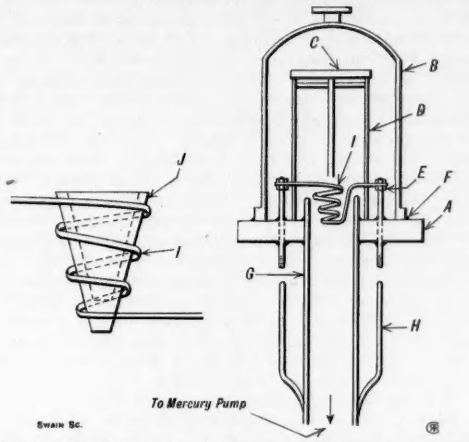
FIG. 2 (*Aluminium*).

Thus, tarnish is completely eliminated and cleaning is readily performed by washing with water or soap and water; the evaporative process ensures that no damage occurs to the accurately figured mirror, whether it be made of glass or metal. Finally, the ultra-violet reflection of aluminium is greatly superior to that of silver, as shown in Fig. 2. It must be borne in mind that the reflectivity values for silver are those taken just after the silver has been deposited; in

* Research Department, Metropolitan-Vickers Electrical Company, Ltd.

quite a short time these would fall very considerably and certainly below those for aluminium.

All early attempts at the evaporation of metals in vacuo were made in apparatus constructed on the general principles of that shown in Fig. 3. Here a large glass bell jar is supported on a flat glass base connected by pipe work surrounded by a liquid air trap to a mercury condensation pump. Inside the bell jar are arranged a support system for the mirror and a heater system consisting of a tungsten spiral



A, Glass Plate; B, Bell Jar; C, Mirror; D, Tripod; E, Sealed in Electrode; F, Wax Seal; G, Sealed in Glass Tube; H, Liquid Air Trap; I, Tungsten Heating Coil; J, Crucible.

FIG. 3

enclosing and supporting a crucible of refractory material; the metal to be evaporated is put into the crucible. The apparatus functions quite satisfactorily provided the metal to be evaporated has a low boiling point in vacuo; if the boiling temperature is 1000 deg. Cent. or over, difficulty is experienced in getting the metal up to the necessary temperature without burning out the tungsten spiral, even though the latter has a melting point of over 3000 deg. Cent. The trouble lies in the bad thermal conductivity of

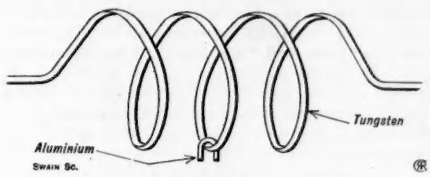


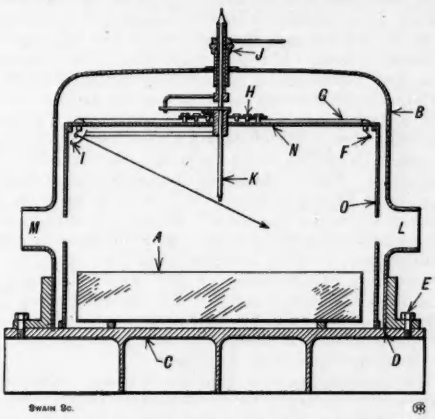
FIG. 4

the refractory crucible, and in consequence this method can hardly be said to have ready commercial application.

Further experimental work produced what might be a possible solution to the problem. It was decided to modify the tungsten heating spiral and to make it as an open coil; on one of the convolutions there was suspended—Fig. 4—a U-shaped piece of the metal to be evaporated. It was found that by gradually raising the temperature of the tungsten coil it was possible in some cases to globulate the metal on the tungsten; provided the metal did not drop off the coil during this process it was a simple matter to increase the temperature still further and effect the evaporation. Some troubles were still experienced, however, among them being the tendency of certain metals to form low melting point alloys with the tungsten; if this occurred the life of the spiral was comparatively short and in some cases the coil burned out during an actual evaporation.

Aluminium was found to be a metal which readily alloyed with tungsten in certain circumstances, and since, as has already been indicated, this metal was particularly suitable for astronomical mirrors, the problem of dealing with its deposition was attacked by several experimenters. In 1933, Dr. John Strong, of the Californian Institute of Technology, reported that his experiments had reached a successful conclusion, the main factor being the use of thick tungsten wire for the heating coils. Dr. Strong claims that this enables him to use the same coil for two or three depositions, and the arrangement was considered good enough to justify the construction of a large equipment for coating most of the existing astronomical mirrors.

The principal features of Dr. Strong's apparatus for coating mirrors up to 38in. in diameter are shown in Fig. 5. Here again a suitable vacuum chamber is



A, Mirror to be Aluminised (36in. dia.); B, Bell Jar 39¼in. inside dia.); C, Baseplate; D, Groove for lead fuse wire Gasket; E, Bolts to fasten Bell Jar to Baseplate; F, Filaments of Tungsten Wire from which Aluminium is Evaporated; G, Conductors to supply current to Filaments; H, Switch; I, Baffle; J, Packing Gland for Switch Control; K, Electrode for cleaning the Mirror Face; L, Observation Window; M, Pump Connection; N, Plate to carry Filaments and Switch; O, Removable Brass Cylinder to carry N.

FIG. 5

used and is pumped to at least 10^{-4} mm. of mercury. Several tungsten coils are employed and are, of course, electrically heated; they are made of 0·030in. diameter tungsten wire and are 2·5in. long, and $\frac{5}{16}$in. in diameter. They are formed on a mandrel in an ordinary Bunsen flame. The aluminium charge consists of U-shaped wires clamped to each turn of the helix, the wires being $\frac{3}{8}$in. long and 0·0312in. diameter.

Twelve coils are arranged around the periphery of a circle, 36in. in diameter, and are mounted on a large disc, together with a switch for the power supply to the coils. This disc is supported on a removable brass cylinder, 38in. in diameter and 24in. high, and the coils are 18in. above the edge of the mirror face. The calculated uniformity with this arrangement varies from a relative thickness of 1·030 to 0·999, and

experimental investigation has shown that this uniformity is attainable in practice.

The switch is operated from outside the vacuum chamber through a packing gland, and connects the tungsten coils separately to the electrical supply. A movable baffle actuated by the switch shields each coil while the aluminium is melted, so that the latter is trapped should it fall off. The baffle is also in position during the initial distillation stage, which is carried out in 4 seconds, during which time the voltage supplied to the coil is 20 volts. A reverse motion of the switch causes the baffle to travel 90 deg. out of phase with the switch and prevents it from interfering with the actual coating process. The correct heat for the evaporation of the aluminium from the coil is obtained by the application of 20 volts for 15 seconds. The entire process of distilling from the twelve coils may be completed in slightly more than 3 minutes.

The mirror to be coated rests on the bed-plate made from a steel plate, 1in. thick and 48in. diameter. The base is reinforced by steel ribs of 6in. by ⅜in. section, and the mirror is supported on brass bars fixed to the bed-plate in order to allow the evolved gases to be pumped more freely.

The vacuum chamber is made of ¼in. thick steel plate, and has a tank head top, 40in. in diameter, welded to a suitable rolled cylinder. In order to allow for machining, the bottom of the cylinder is stiffened by means of rolled angle iron. The vacuum-tight seal is effected by causing the machined surface of the cylinder bottom to press a soft wire, such as a lead fuse wire, into a groove in the bed-plate. Twenty-four bolts compress this gasket with a force of 50 tons, to which is added 10 tons when the chamber is evacuated. The inside of the chamber is coated with a layer of Apiezon wax "W," which, in turn, is covered by a few layers of evaporated aluminium. The wax has a negligible vapour pressure at room temperature and even at 180 deg. Cent. its vapour pressure is only of the order of 10^{-3} mm. of mercury. A medium is thus available for ensuring vacuum-tightness of the cylinder, and at the same time does not present serious danger of any gas evolution in the chamber when it is evacuated.

The pumping system consists of a 4in. valve and trap, a 6in. diameter oil condensation pump operating on Apiezon oil "B," and 2½in. diameter pump operating on Apiezon oil "A," together with a suitable rotary pump. The condensation pumps are permanently connected to the side of the chamber, which has a 4in. diameter observation port opposite the pump connection. A spark discharge tube with a 3in. alternative spark gap, is used as a vacuum indicator, and shows complete black-out at 10^{-3} mm. pressure. The latter is attainable by the Hypervac mechanical pump and liquid air trap in about one hour's pumping from atmospheric pressure. Once this pressure is reached the condensation pumps are energised to bring the pressure down to about 10^{-5} mm. of mercury.

It is thus seen that the apparatus necessary for performing high vacuum evaporation on a laboratory scale is relatively simple, but even so, unless great care be taken and a proper technique adopted, the results obtained are very disappointing. For large mirrors or for coating a large number of small mirrors on a commercial scale, the complication naturally increases. The main desiderata are absolute cleanliness of the surface to be coated and the ability of the pumping system to attain a high vacuum of the order of 10^{-5} mm. of mercury in a short time and to maintain it for the period necessary for coating the mirrors.

Two plants are at present in operation in the Research Laboratories of the Metropolitan-Vickers Electrical Company. The smaller deals with mirrors up to 9in. in diameter and the other with mirrors up to 15in. in diameter. In addition, a large plant is practically completed, and deals with mirrors of up to about 50in. in diameter. Vacua of about 10^{-5} mm. of mercury are most readily obtained in an apparatus of this size by means of the oil condensation pumps developed in the company's laboratories as a result of the work of Burch on low-vapour pressure oil distillates in 1929. It will be remembered that such pumps are used by Strong. The large evaporating plant is in the form of a cylinder some 4½ft. in diameter and 3ft. long. The condensation pumps used to evacuate this are of the new multiple type, and have a pumping speed of about 150 litres per second at any pressure between about 10^{-3} mm. and 10^{-6} mm. of mercury. It will be noted that the low vapour pressure of the oil used as the working fluid of the pumps enables such high vacua to be obtained without the use of liquid air or other cold traps for the removal of vapours, a procedure necessary when mercury diffusion pumps are employed. The cylinder is fabricated of steel, all welds being made by the atomic hydrogen process which has been found most suitable for the production of vacuum-tight joints. Gauges and vacuum indicators are, of course, necessary and the actual operation of the plant must be under the control of a highly skilled operator.

The actual evaporation in all plants is effected from a new heater system developed so as to render the plant commercially feasible, by C. H. Walker, who is also responsible for other developments contributing to the success of the process. This heater system does not involve the use of tungsten coils, and it is so designed that there is no trouble experienced in globulating the aluminium. In addition, it is impossible for molten aluminium to fall on to the mirror surface either in the preliminary or in the final stages of the evaporation. Stress must be laid on the difference between mirror production in a laboratory where it is not necessary to have 100 per cent. success with all mirrors and commercial production where each mirror coating must be successful if reasonable price levels are to be attained.

The process has been used with great success for other metals as well as aluminium. Very fine films of copper, chromium, tin, silver, and lead have been prepared, but, with the exception of the chromium, all must be protected from the attacks of tarnishing agents. In addition, aluminium has been deposited on fabrics, paper, bakelite, and porcelain, and investigations are proceeding on the possibility of finding new applications for coated materials of this type.

The Alpha-Phase Boundary in the Copper-Tin System.

IN *Metallwirtschaft* of March 8th there appears a paper by T. Isawa and I. Obinata on "X-Ray Investigations on Tin Bronzes."[1] The first part of this deals with the solubility limits of the α-tin-copper solid solution, previous information about which is summarised by the authors in Table I. In their own work alloys prepared from the pure metals were rolled and

[1] *Metallwirtschaft*, 1935, 14, 185–188; previously published in Mem. Ryojun Coll. Eng. (Inouye Commemoration Volume), 1934, 235–242.

annealed for eight days at 650 deg. Cent. The alteration in lattice parameter was then determined in alloys which had been reheated at a given temperature and quenched in water. For example, specimens of the annealed alloys were reheated at 500 deg.

TABLE I.—*Solubility of Tin in Copper.*

	Solubility, per cent.			Year.
	At the peritectic temperature.	At the eutectic temperature.	At room temperature.	
C. T. Heycock and F. H. Neville	9	9	9	1903
S. Shepherd and E. Blough	10	12	13	1906
F. Giolitti and G. Tavanti	15	13	10	1908
S. L. Hoyt	8·5	10	10	1913
S. L. Hoyt	12·5	13	13	1921
M. A. Corey	10	16	16	1915
O. Bauer and H. Vollenbruck	14	14	14	1921
T. Isihara	11	14	14	1924
D. Stockdale	13·3	16	16	1925
J. L. Haughton	13	15	15	1925
M. Hansen	13·3	16	14	1927
T. Matsuda	14	15	15	1928
O. A. Carson	13	16	14	1929
M. Hamazumi and S. Nisigori	13	15·2	15·2	1930

Cent. for two days and quenched in water. The lattice dimensions are shown in Fig. 1, from which it is deduced that the limiting solubility of tin in copper at 500 deg. Cent. is 8·95 atomic per cent. or 15·50 per cent. by weight. In a similar way the limits for other reheating temperatures were obtained. Alloys of

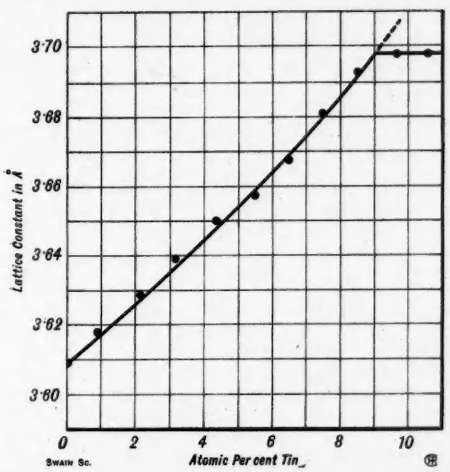


FIG. 1.—*Influence of Concentration on Lattice Constant of Tin-Copper Alloys, Annealed two days at 500 deg. Cent. and Quenched in Water.*

high tin content (14 to 18 per cent.) and heterogeneous structure were held for twelve days at 400 deg. Cent., or two days at temperatures above 400 deg. Cent. The final results are given in Fig 2 and Table II. The solubility diminishes rapidly between 525 and 400 deg. Cent., and then remains almost constant at nearly 14 per cent. of tin down to atmospheric temperature.

The supersaturated alloys containing 16·88 and 18·06 per cent. of tin respectively, which had been brought into equilibrium at 650 deg. Cent., did not show a sharp spectrogram after being reheated at 400 deg. Cent. for one day or even for seven days. Only after twelve days at 400 deg. Cent. was the α-doublet again clearly detectable. Micrographically,

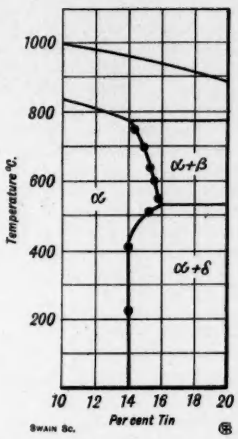


FIG. 2—*Alpha-phase Boundary of Tin-Copper Alloys.*

the amount of the δ-phase precipitated only became appreciable after twelve days heating at 400 deg. Cent. Precipitation was not clearly observable after seven days at that temperature. Sharp spectrograms could not be obtained after annealing for twelve

TABLE II.—*Solubility of Tin in Copper at Different Temperatures (Isawa and Obinata).*

Temperature, deg. Cent.	Solubility. Atomic per cent.	Per cent. by weight.
750	8·30	14·45
700	8·75	15·20
645	8·90	15·43
600	9·05	15·70
550	9·20	15·90
500	8·95	15·50
400	7·95	13·90
218	7·95	13·90

days at lower temperatures, *i.e.*, at 300 deg., 218 deg., and 100 deg. Cent.

Hence it was concluded that precipitation of δ from the supersaturated α solution occurs very slowly at the lower annealing temperatures, and that lattice distortion, revealed by a lack of sharpness in the lines of the spectrogram (an effect which was also observed to result from internal stresses), occurs during the initial stages of the precipitation process.

This short abstract affords an opportunity of directing attention to a method of determining solubility limits which is certain to be widely applied in future. The method, of course, is not new. It was probably first applied by Westgren, and it was discussed in THE METALLURGIST in some detail four years ago.[2] The method involves very accurate measurements of the lattice parameters, but such measurements of the α-tin-copper alloys (in close agreement with the present results) had already been made in 1925 by H. Weiss.[3] The X-ray work has brought no radical alteration to the shape of the solid solubility curve of tin in copper ;

[2] THE METALLURGIST, 1931, 7, 26.

[3] *Proc.* Roy. Soc., 1925 (A), 108, 643.

but in another recent instance of its application, in the less carefully explored copper-iron diagram, very definite changes in the solubility limits have been based on X-ray evidence. Using this method, Norton[4] found that the solubility of copper in iron at about 850 deg. Cent. is 1·4 per cent., and not 3·3 per cent., as found from the electrical resistivity, and that it falls to 0·35 per cent. at 650 deg. Cent.

In general, the X-ray method of determining solubility limits is probably more accurate than other physical methods, particularly the method of microscopical examination of annealed alloys which depends on the detection of the last trace of a second constituent. The X-ray method also necessitates the use of fewer compositions, though a tendency to cut down the number unduly on the assumption that the change in lattice parameter of a solid solution is always linear may lead to error. Very prolonged annealing treatments are, however, just as essential in the preparation of the specimens if equilibrium is to be attained, and sharp and trustworthy spectrograms secured.

Pickling of Steel Castings.

IT has long been a custom to subject certain special steel castings to a pickling process for the purpose of removing all traces of moulding sand. This procedure has been applied particularly to castings for use in connection with turbine machinery, where the presence of sand on the internal surface, not easily accessible to ordinary cleaning, might lead to disastrous results. No ill effects were known to have been occasioned by this practice, and it was therefore with some apprehension that users of castings in this country received the sweeping condemnation of the practice which was expressed some years ago by Captain Louis Shane, of the U.S. Navy.* He stated that "pickling of ordinary castings is highly undesirable. It will cause more defects than it will show up. Defects caused by pickling are progressive. Pickling has ruined many a good casting." It was stated that "products of corrosion enter the turbines with the steam and erode the blades," and in other quarters it was alleged that steel castings develop surface cracks during pickling and that the products of corrosion, lodged in these fine crevices on the surface of the casting, give rise to corrosion-fatigue.

The matter has now been investigated by C. W. Briggs and R. A. Gezelius, who have published their conclusions in a paper on "Surface Cracking of Steel Castings During Pickling."† They used a cast steel containing carbon 0·23, manganese 0·76, and silicon 0·31 per cent., annealed for half an hour at 900 deg. Cent., and pickled in 10 per cent. sulphuric acid at 65 deg. Cent. for one hour. The specimens were tested in the pickling solution without any opportunity for recovery from hydrogen embrittlement, with the following typical result :—

	Tensile strength, tons per sq. in.	Elongation, per cent.	Reduction of area, per cent.
Not pickled	31·25	30·5	42·5
Pickled, no inhibitor	29·3	12·0	15·5

Restrainers reduced the degree of embrittlement to a slight extent, but did not avoid it. If the specimen after being pickled was washed in cold water and allowed to remain at room temperature, it quickly recovered some of its lost ductility, but the elongation and reduction of area never attained the original values shown by the specimen which had not been pickled. For example, specimens pickled, washed, and tested in air never reached the elongation and reduction of area recorded above for the steel before pickling, but gave the following results :—

	Tensile strength, tons per sq. in.	Elongation, per cent.	Reduction of area, per cent.
After standing 8 min.	30·6	21	22
After standing 24 hours	30·8	23	26

The authors attribute this permanent reduction of ductility to the formation of minute surface cracks which only become apparent when the stress rises to the breaking point, and the additional temporary reduction to hydrogen embrittlement.

It was found that pickling under a uniformly applied stress of 15·2 tons per square inch caused no greater fall in elongation than pickling an unstressed specimen, and that actual deformation (up to 2 per cent. extension) before pickling had no deleterious effect on the annealed or the "as cast" specimens. On the other hand, castings purposely designed to develop internal stress and found, by cutting, to be under tensile stress of the order of 4½ tons per square inch, were pickled forty-five minutes, washed with cold water, cut off and tested within twelve minutes of removal from the pickling solution with the following results :—

	Tensile strength, tons per sq. in.	Elongation, per cent.	Reduction of area per cent.
As cast :			
Not pickled	30·1	17·0	23
Pickled	27·2	7·5	13

Specimens in which compressive stress was present during pickling showed no drop in tensile strength and practically no change in ductility.

It was concluded that the bad effect of pickling was due mainly to the action of surface tensile stress in the casting, and that a piece of steel which was entirely free from internal stress would exhibit no embrittlement on pickling. The final recommendation in the paper is that "because of the high internal stress in many steel castings, pickling be discontinued and sand-blasting or tumbling be substituted. If sand-blasting will not clean intricate openings, the casting should be given a full anneal prior to pickling, to reduce internal stresses, and an inhibitor should be used in pickling."

It seems possible that the difference between British and American experience of the effect of pickling has been due to the degree of annealing that the castings have received.

There can be no question as to the relative efficiency of sand-blasting or other mechanical method, and pickling in removing moulding sand from intricate castings, and it seems clear from the work of Briggs and Gezelius that, provided the casting is fully annealed before the pickling process, no harm will result.

[4] Amer. Inst. of Min. and Met. Eng., Tech. Pubn. No. 586.

* L. Shane, *Journ.*, Amer. Soc. Naval Engineers, 1933, 45, 22.

† C. W. Briggs and R. A. Gezelius, *Metals and Alloys*, Feb., 1935, 6, 39–40.

ERRATUM : "THE METALLURGIST."—On page 5 of the February issue of THE METALLURGIST, column 2, lines 8 and 9, for "one or two million" read "one to two hundred thousand."